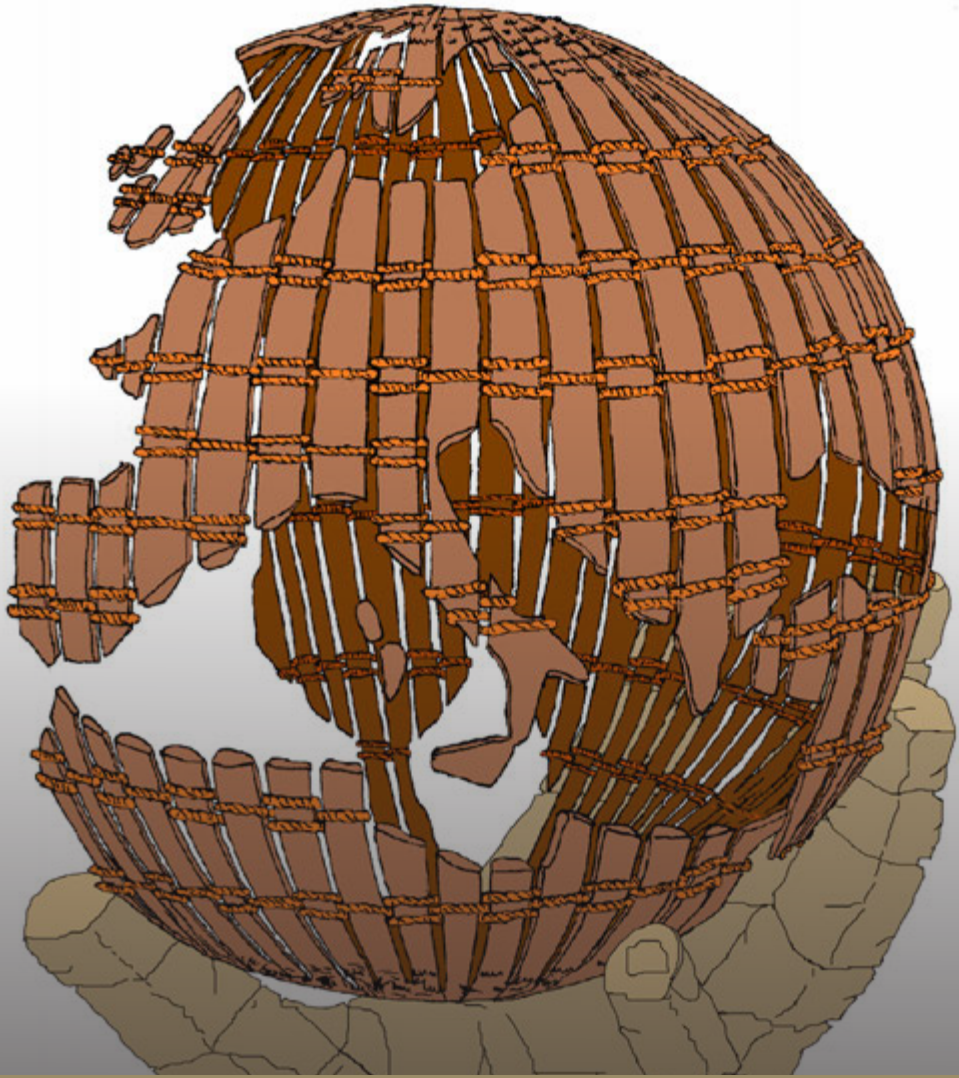
Estratto

Terra, legno e materiali deperibili nell'architettura antica



a cura di
CATERINA PREVIATO
JACOPO BONETTO

2. L'età romana

ATTI DEL CONVEGNO INTERNAZIONALE DI STUDI
(PADOVA, 3-5 GIUGNO 2021)

COSTRUIRE NEL MONDO ANTICO 6

ROMA 2023
EDIZIONI QUASAR

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Jacopo Bonetto – Caterina Previato
Università degli Studi di Padova – Dipartimento dei Beni Culturali
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La Collana *Costruire nel mondo antico* raccoglie monografie, miscellanee e atti di convegni che costituiscono l'esito di ricerche sull'architettura e sull'edilizia nel Mediterraneo e nell'Europa antichi. Nella collana è prevista la pubblicazione di volumi dedicati a singoli edifici e complessi architettonici, di opere di sintesi sui modi del costruire in uso in centri urbani o in regioni del mondo antico e di contributi che affrontano gli aspetti più tecnici del costruito antico (approvvigionamento e produzione dei materiali da costruzione, tecniche edilizie, pratiche di cantiere, processi costruttivi). L'obiettivo della serie di opere tematiche è riunire e valorizzare gli studi sull'edilizia quale strumento chiave per la comprensione della storia delle comunità antiche nelle sue dinamiche economiche, produttive, sociali, tecnologiche, culturali, territoriali.

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CATERINA PREVIATO
JACOPO BONETTO

con la collaborazione scientifica di
ELIANA BRIDI, CHIARA GIROTTO, BEATRICE MARCHET

2. L'età romana

Roma 2023
EDIZIONI QUASAR

SIMONE DILARIA, ENRICO GARBIN, LARA MARITAN, ARTURO ZARA

Analytical investigations on mudbricks from a Middle Imperial building from Nora (Sardinia). Composition, production process and mechanical properties

1. Introduction

Analytical investigations on ancient building materials are obtaining an increasing consideration in archaeology, as archaeologists are demonstrating an increased interest in understanding the composition, the physical properties and the provenance of the raw materials used in ancient constructions. In fact, the correct analysis and interpretation of these elements can offer important indications for an in-dept understanding of ancient communities, providing tangible insights on the technical skills of the crafts, the socio-economical influence of committee and the organization of manpower among the cultures of the ancient world.

At present, the traditional archaeometric research has been mainly focused on lithic, ceramic and derivate products (i.e. mortar-based materials) for diagnostic and characterization or conservation and restoration purposes. On the other hand, perishable materials and, in particular, earthen-based materials (EBM) were only marginally considered in this perspective. Considering the Mediterranean societies, several analytical works have been undertaken in the study of those archaeological contexts where earther-based architecture historically developed, such as the territories of the southern Europe, North Africa and Levant[1]. Most of the contexts relates, in fact, to the Aegean, Levantine and Egyptian cultures, in a chronological range comprised between the Neolithic and the late Bronze Age/Early Iron Age; on the other hand, little has been done in the analysis of the later development of the EBM between the Archaism and the Late Roman ages[2], albeit the construction techniques relying on EBM remained still largely employed in the Greek, Etruscan, Punic and Roman cultures[3].

Besides the eminently compositional features, another aim of the scientific investigations on EBM is the measure of their physical properties. Frequently, archaeometric data have been coupled with mechanical tests to assess the compressive strength and the deformability of EBM[4].

In the wake of this scientific approach in the examination of archaeological building materials, the present paper analyzes the composition and physical properties of the mudbricks used in the construction of a Roman building in Nora (Sardinia) dated to the Roman Middle Imperial Age, that collapsed after the abandonment in a later time. By the analysis of the mudbricks, we aim to corroborate the reconstruction proposal of the original conformation and height of the building that, at present, preserves little of its mason-

1 For example: Guest-Papamanoli 1978; Jerome 1993; Joyner 1997; Morgenstein, Redmount 1998; Nodarou, Frederick, Hein 2008; Liberotti et al. 2009; Liberotti 2012; Love 2012; Costi de Castrillo, Philokyprou, Iannou 2017; Cammas 2018; Devolder, Lorenzon 2019; Rosenberg et al. 2020; Lorenzon 2021a; Lorenzon 2021b; Liberotti 2021.

2 For example: Montana 2011; Cammas 2018; Lorenzon, Iacovou 2019; Amicone et al. 2020. The papers of M. A. Mastelloni; M. Lorenzon et al.; A. J. Ortiz Villarejo, L. M. Gutiérrez Soler; E. Rodríguez González et al. in this volume provide further analytical data on the topic for the considered chronological timeframe.

3 Germanà 2011; Russel, Frentless 2016; Ceccarelli 2019. In detail, regarding earthern architecture in ancient Sardinia: Tirabassi 2021, Secci 2022.

4 Quagliarini, Lenci, Iorio 2010; Liberotti et al. 2016; Liberotti 2021. A noteworthy core of works has focused on the structural properties of earthen-based vernacular architecture of pre-Columbian Mesoamerican civilizations (Chácara et al. 2014; Liberotti, Daneels 2012; Aguilar, Montesinos, Uceda 2017; Aguilar et al. 2018; Zanchetta et al. 2020).

ries *in situ*. The characterization of the materials was performed throughout a multi-analytical approach integrating archaeometric investigations, comprising transmitted light optical microscopy, quantitative phase analysis of X-Ray powder diffraction (QPA-XRPD) and mechanical compression tests performed at the laboratories of the Department of Geosciences and of the Department of Civil, Environmental and Architectural Engineering of the University of Padova.

[S.D.]

2. The Middle Imperial building in the eastern quarters of Nora

Since 2014, the Department of Cultural Heritage of the University of Padova is carrying on archaeological excavations in the eastern district of the ancient city of Nora, located in the southern part of Sardinia (Italy)[5]. Nora rises up on a large peninsula on the south-western edge of the Gulf of Cagliari. The site, considered by Pausania the «first city of Sardinia» (Paus. 10.17-5), was a Phoenician settlement at least since mid-8th century BC, then it developed between the Punic (since the late 6th cent. BC) and the Roman periods (since the late 3rd century BC) into an urban town, provided of streets, temples and residential quarters. Between the end of 2nd and the 3rd century AD, archaeological and epigraphical evidence delineate a period of urban development and prosperity and the town was greatly upgraded with several new public and private buildings.

The current investigations are bringing to light a large building (more than 220 m^2), located eastwards of the Roman *forum*[6], having both residential and commercial functions. The building dates back to the Roman Imperial Age and it underwent to a complete renovation in the late 3rd century AD. The later phase is based on the discovery of a hoard under the pavement of a room, whose chronology has been fixed between 282 and 283 AD[7]. This restoration gave the building its final layout, with new rooms and a first floor in its southern part. Finally, the abandonment of the building occurred probably in the course of the Late Antiquity (fig. 1).

From what we observed, the lower part of the walls of the building is still *in situ* (about 1 m over the floor) and it is made of large irregular cobbles (mainly local Oligo-Miocene volcanic dacite/andesite rocks and Tyrrhenian sandstones) bound with lime mortar or, to a minor extent, mud mortar. The upper parts of the walls collapsed probably after the abandonment of the building. They were mainly made in mudbricks or pisé, and they were externally plastered with wall-paintings, which were supposed to cover also the lower part of the masonry.

[A.Z.]

3. Analysis on mudbricks

3.1 Sampling

The post-depositional events which affected the building during the last 1500 years seriously biased the sampling of the mudbricks. In fact, after the abandonment, the edifice faced a progressive collapse due to the lack of maintenance: the strata relatable to collapse debris have been completely investigated down to the original ground floor. Unfortunately, the combination of various weathering agents (i.e. rain) produced the substantial disaggregation of mudbricks to such an extent that they were hardly distinguishable within the sedimentary matrix constituting the archaeological deposit[8] (fig. 2a). Nevertheless,

5 Archaeological research of University of Padova in Nora started at the beginning of the 1990's. The thirty-year results of the scientific activities in the ancient city are regularly published in the book series "Scavi di Nora"; reports of archaeological excavation are published in the journal "Quaderni Norensi". The research project currently involves four Universities (Cagliari, Genova, Milano, Padova), under the coordination of "SABAP della città Metropolitana di Cagliari e le provincie di Oristano e Sud Sardegna".

6 For the archaeological analysis of the building: Zara 2018; Zara 2020; Volpin, Zara 2020; Stella Mosimann, Zara 2019; Stella Mosimann, Zara 2020; Marchet, Zara 2022.

7 Asolati, Bonetto, Zara 2018.

8 Friesem et al. 2014.

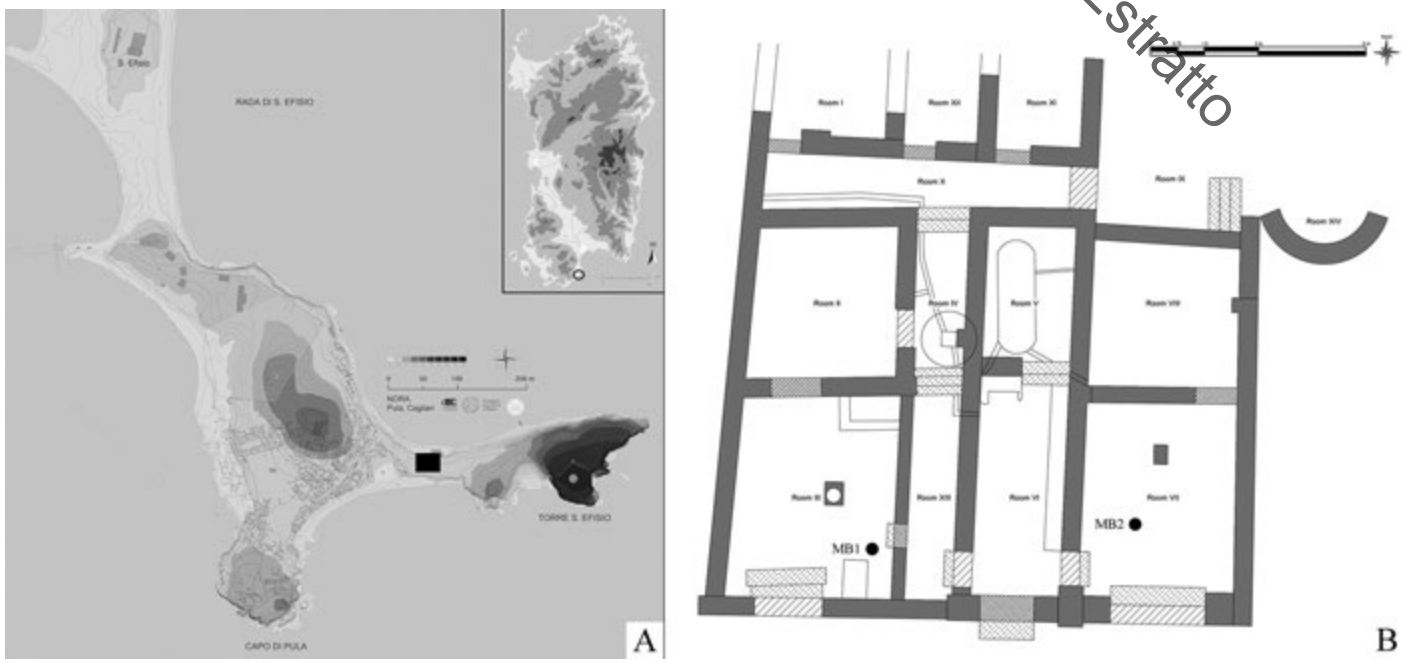

Fig. 1. A) The site of Nora in the south-western Sardinia with indication, in the square, of the Middle Imperial building; B) Plan of the Middle Imperial building with indication of the sampling point of mudbricks (by A. Zara).

we were able to identify on site traces of the mudbricks in regular rows on the backing layers of some collapsed wall-paintings (fig. 2b)[9], but it was possible to sample undissembled mudbricks only in a few occasions: therefore, the analyses were limited to two sufficiently cohesive samples, defined MB1 (from room XIII) and MB2 (from room VII).

Before proceeding with the analytical investigations, the samples were preliminary described according to their macroscopic features. From a direct observation, the bigger sample, MB1, has an heterogeneous composition as it presents two areas displaying different colors. Therefore, each area has been subsampled for analysis. The reddish area (7.5YR 7/8) was labeled MB1-RC while the dark-brown one (7.5 YR 3/2) was labeled MB1-BC[10]. On the other hand, MB2 has a more homogeneous matrix. Both the samples present abundant coarse inclusions, such as reused mortars and ceramic fragments. This indicates that recycled building materials and artefacts were used in the manufacture (fig. 3).

[A.Z.]

3.2 Petrographic analysis on thin sections

Petrographic investigation was carried out on standard 30 µm thick thin sections using a polarized light optical microscope, adopting the description procedure and terminology proposed by Whitbread[11] and revised by Quinn[12]. Semiquantitative analysis on textural features, in particular on inclusions and voids, was performed by digital image analysis (DIA) on transmitted light scans of the thin sections (samples MB1-BC, MB1-RC, MB2) acquired in plain-polarized light and treating the images with the software ImageJ[13].

9 This paper focuses on the archaeometric and mechanical analysis of mudbricks found in the collapse debris, while the paper by S. Berto, F. Stella Mosiman and A. Zara in these proceedings provides a metric analysis of the traces of mudbricks in the backing layers of plasters.

10 Munsell Soil Color Chart (Munsell 1975).

11 Whitbread 1986; Whitbread 1989; Whitbread 1995.

12 Quinn 2013.

13 This technique was adopted to obtain an estimation of the prominent features (percentages of inorganic and organic inclusions and voids) of the samples with the awareness of the detection limits that this method presents (v. Maritan et al. 2020 and references

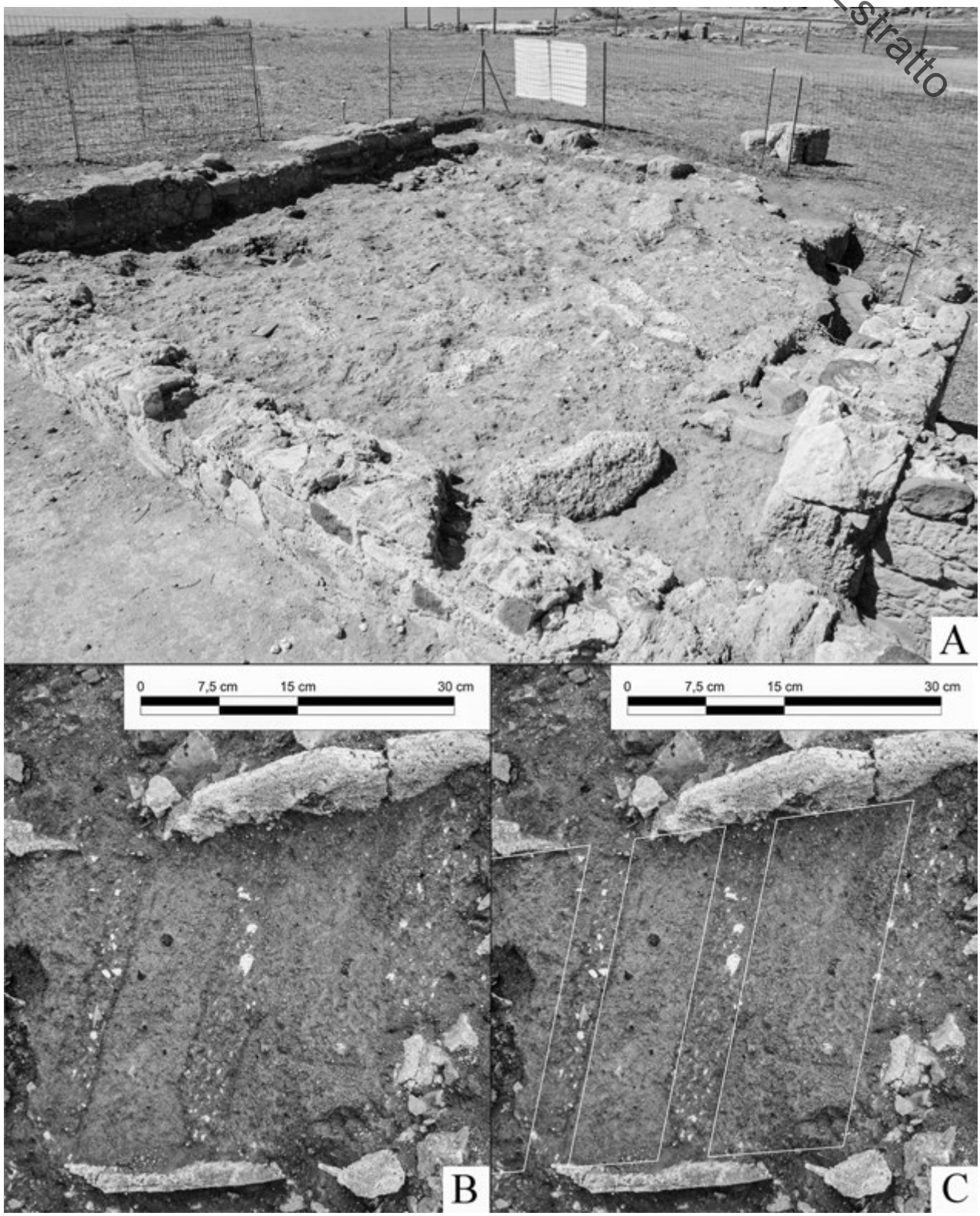

Fig. 2. A) Disaggregated layers of the collapsed earthen-based portion of the walls found during the excavation of a room of the Middle Imperial building; B-C) traces of collapsed mudbricks bond by mud mortar (by A. Zara).

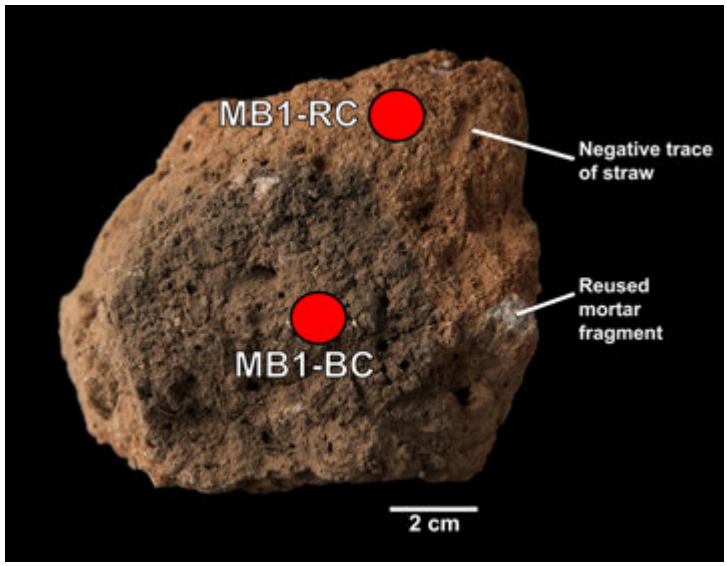

Fig. 3. Sampling of the two areas of the mudbrick MB1 having two different colours. Reused fragments of mortars and negative traces of straw are clearly recognizable within the matrix of the material (by S. Dilaria).

From a microscopic point of view, the samples share very similar features for both the groundmass and the inclusions they contain. The groundmass is homogeneous, optically active, with a speckled *b*-fabric (birefringent-fabric). Porosity consists of abundant voids, mainly represented by large millimetric and sub-millimetric vughs and channels; some voids seem to derive from the decomposition of organic temper (such as straw or grass). Inclusions are mainly represented by medium to fine rounded sands having a closed space related-distribution and a seriate grain-size distribution, with a maximum size up to 3,0 mm. Inclusions are composed by abundant crystal of quartz, associated to fragments of alkaline granite, sandstone, ARF (argillaceous rock fragments), carbonate mudstone, fossiliferous limestone, metamorphic rocks (quartz-rich level, metapelite and metabasite), vitreous effusive rocks, K-feldspar (microcline-pertite), plagioclase, rare crystals of pyroxene, biotite and chlorite (partially decomposed), opaque minerals (fig. 4, a-f). As clearly detected by macroscopic analysis, fragments of mortar and grog are also present (fig. 4, g-h).

DIA on thin sections scans allowed to estimate the percentages of inclusions and voids for each sample (tab. 1). The differences that can be observed among the samples are mainly related to the variable abundance of the inclusions in the body, which indicates a non-standardized processing of the mixtures[14].

The comparison with the sand collected in the vicinity of the site clearly indicates that the carbonate inclusions are not consistent with the composition of the locally available sands, composed mainly of silicate minerals and intrusive and effusive rock fragments[15]. They can, therefore, derive from the carbonate rocks outcropping some kilometers north-western of the site, representing a temper deliberately added and deriving from the same raw material used to produce the lime.

[L.M.]

3.3 QPA-XRPD

All the three samples were examined also from a mineralogical point of view. Data were collected using a Bragg–Brentano θ-θ diffractometer (PANalytical X'Pert PRO, Cu Kα radiation, 40 kV and 40 mA)

Sample	Inorganic temper (%)	Organic temper (%)	Voids (%)
MB1-BC	35-40	< 5	15
MB1-RC	30-35	< 5	15
MB2	30	5	10

Tab. 1. Quantification of inclusions and voids of mudbrick samples by DIA of thin-section scans. Organic temper was determined manually isolating the voids with large size which derived from their decomposition.

therein).

14 Nevertheless, the samples are small with respect to the grain size of inclusions and therefore these differences can be also due to a limited representativeness of the analysed area.

15 Melis, Columbu 2000; Columbu 2018.

equipped with a real-time multiple strip (RTMS) detector (PIXcel by Panalytical). Data acquisition was performed by operating a continuous scan in the range 3-85 [◦2θ], with a virtual step scan of 0.02 [◦2θ]. Diffraction patterns were interpreted with X'Pert 164 HighScore Plus 3.0 software by PANalytical, qualitatively reconstructing mineral profiles of the compounds by comparison with PDF databases from the International Centre for Diffraction Data (ICDD). Then, quantitative phase analysis (QPA) was performed on the samples using the Rietveld method[16]. Refinements were carried out with TOPAS software by Bruker AXS. The determination of both crystalline and amorphous content was calculated by the addition of 20 wt% of zincite to the powders as internal standard.

The QPA-XRPD analysis confirms the petrographic investigations. The samples returned an homogeneous pattern of mineralogical phases (fig. 5, tab. 2). They mainly contain quartz, calcite, K-feldspars, plagioclases. These phases are related to the local sands added to the matrix of the mudbricks as temper. The peaks of calcite could be mostly related to the fragments of limestones used as coarse temper and obtained from the same rocks used to produce the lime, as well as from the recycle of mortar fragments. Biotite, illite-type micas and ilmenite are related to the micromass of the samples, as well as most of the amorphous fraction.

The variable percentage of each phase in the three samples demonstrates the non-standardization of the making technique and the partial diversity within the mudbricks.

The presence of hematite could be related to different factors. This is a ferric hydroxide

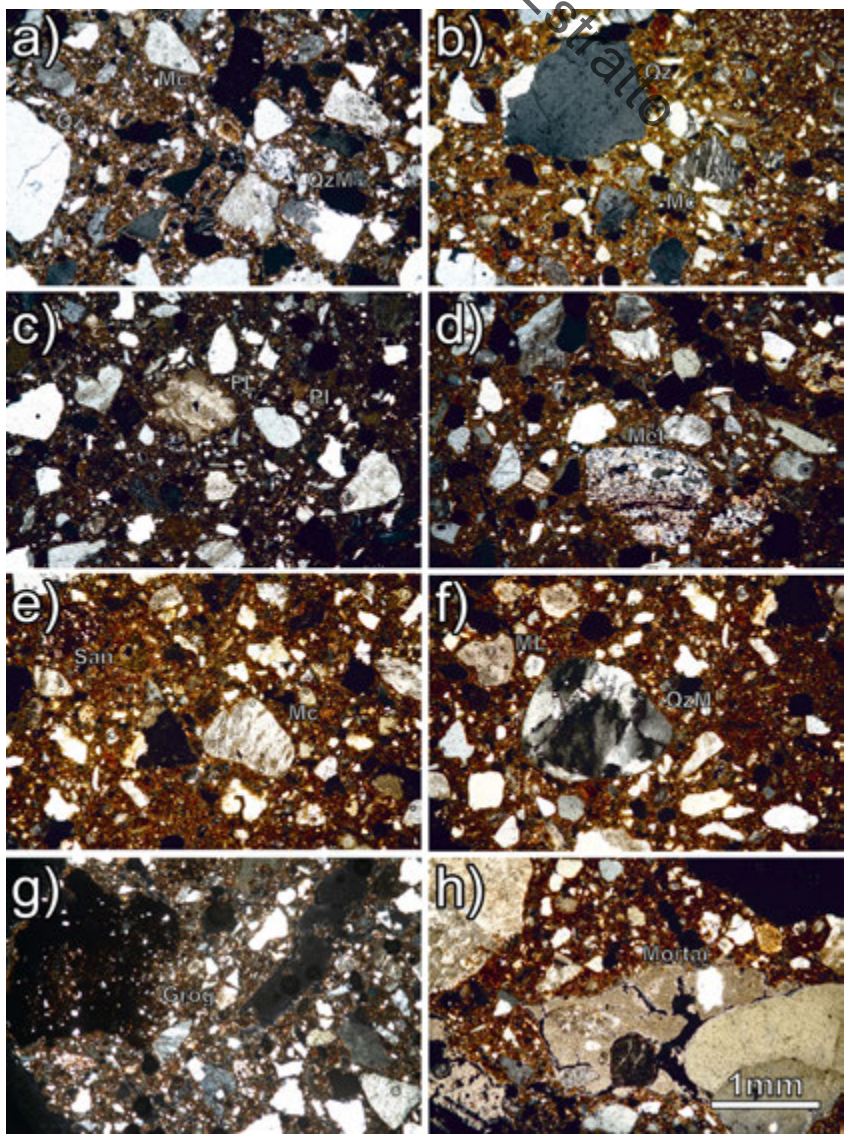

Fig. 4. Photomicrographs in crossed-polarised light of mudbrick samples: a-b) MB1-RC; c-d) MB1-BC; e-f) MB2; g-h) grog and mortar fragments inclusions. *Abbreviations:* Mc = microcline; Qz = quartz; QzM = metamorphic quartz; Pl = plagioclase; FL = fossiliferous limestone; San = sandstone; Mct = metapelite; ML = micritic limestone (by L. Maritan).

Sample	Calcite	Quartz	Plagioclase	K-feld-spars	Micas	Illite	Hematite	Ilmenite	Amor-phous	SUM
MB1-BC	24,6	30,9	10,0	14,3	5,6	0,2	0,7	0,7	13,0	100,0
MB1-RC	9,5	40,5	11,7	18,5	6,2	0,5	1,5	0,6	11,0	100,0
MB2	7,0	43,6	15,7	20,0	9,2	0,9	1,2	0,0	2,6	100,0

Tab. 2 - Results of QPA-XRPD analysis of mudbrick samples.

16 Rietveld 1967.

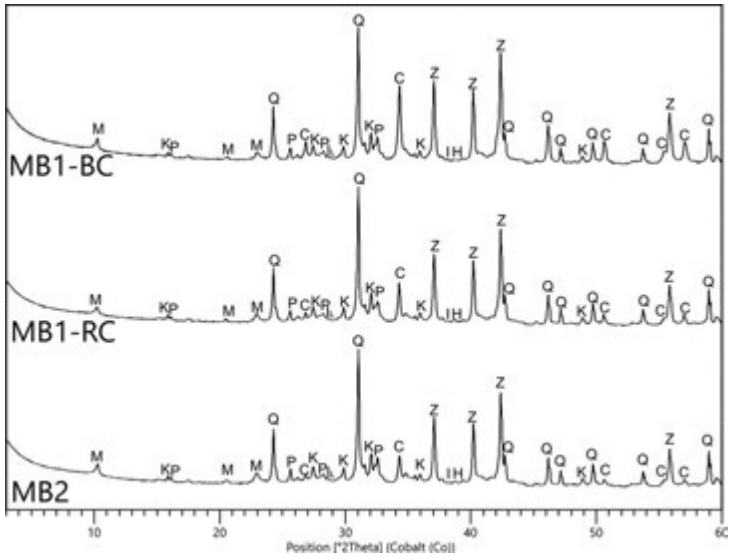

Fig. 5. XRPD diffraction patterns of the three mudbrick samples with indication of the main peaks for each mineral phase. *Legend*: C = calcite; H = hematite; I = ilmenite; Il = illite; K = K-feldpsars; M = micas; P = plagioclases; Q = quartz; Z = zincite (internal standard) (by S. Dilaria).

which could be probably associated, as well as the micas, illite and ilmenite, to the original clayey material, as it can occur in oxidized deposits of southern Mediterranean regions. Iron oxides, when detected in low amounts in mudbricks[17], are frequently considered as a natural constituent in the parent material exploited for the production.
Nevertheless, it should be also considered that hematite can have a pyrogenic origin as it can form after the heating treatment of clays in oxidizing condition at temperature from 400°C[18]. The amount of this phase is overall too high, in particular in MB1-RC, to depend to the little ceramic inclusions of the samples. Therefore, it cannot be related to the grog fraction. On the other hand, this aspect could indicate that the mudbricks were fired in ovens or kilns at low temperatures and surely lower than those required for the production of proper bricks. In fact, by comparing the mineralogical profiles of some clay samples collected from deposits in the territory around Nora, two important differences can be outlined: the first is the lack, in the sampled mudbricks, of kaolinite, a common clay phyllosilicate frequently detected in clay samples of Nora's territory[19]. The heating treatment of the materials could have provoked the decomposition of this phase. Nevertheless, the absence of kaolinite could simply depend on an instrumental detection limit, as the addition of tempers to the original clay could have diluted such phase. The second difference is the high amount of the amorphous phase in MB1-RC and MB1-BC samples, that could be related to a somewhat dehydroxilation of the original clay minerals, such as kaolinite and illite[20].

[S.D.]

3.4 Mechanical test

Mechanical tests were performed on the bigger sample (MB1) to acquire some information about the compressive strength of the mudbricks' portion of the masonry walls, and in order to verify some working hypotheses regarding the original height of the building.
Five quasi-prismatic samples were handsaw from the sample MB1 and were capped with gypsum in order to be tested with a universal testing machine (fig. 6, a). The average base and height of the samples were of 54,5 mm^2 (coefficient of variation of 28,2%) and 41,1 mm^2 (4,8%), respectively. The samples had an average base-to-height of 1,8, thus confirming the quasi-prismatic geometry of the samples and their suitability for uniaxial unconfined compressive tests. The average apparent density of the samples was of 1,72 g/cm^3 (1,24%). Following the principles of EN 772-1[21], the samples were capped with gypsum having a compressive strength of about 24 MPa and tested with an electro-mechanical

17 Devolder, Lorenzon 2019; Lorenzon 2021b, 88.
18 Nodari et al. 2007.
19 Avogaro 2020/2021.
20 Wang, Wang, Zhang 2017.
21 EN 772-1 2015.

universal testing machine (Galdabini, Varese-Italy) mounting a load cell with a full-scale of 3,5 kN and an accuracy of 0,03% (fig. 6, b-c).
The tests were run in displacement control with a loading speed of about 7,5 µm/s. As shown in fig. 7, the Unconfined Compressive Strength (UCS) of the samples was between 1,40 to 2,10 MPa. The average UCS of the samples was of 1,8 MPa (15,9%). The average modulus of elasticity, computed between 30 to 60% of the maximum stress, was of 175 MPa (34,9%). The experimental data obtained from the compression tests are shown in tab. 3 with their Coefficient of Variation (CoV) within brackets.

[E.G.]

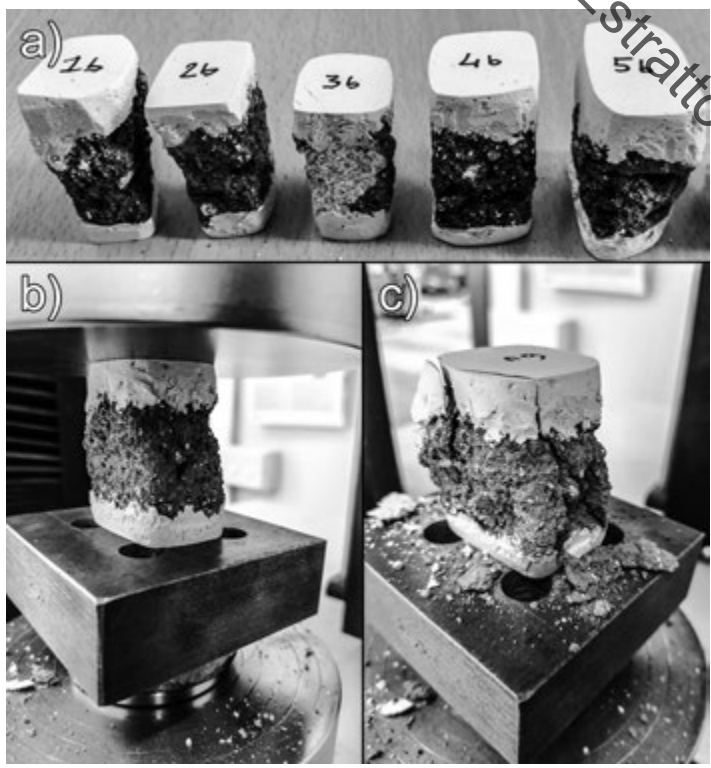

Fig. 6. Mechanical compression test on mudbrick MB1. a) 5 quasi-prismatic samples handsaw from MB1; b) a samples under compressive test; c) a sample after testing (by E. Garbin).

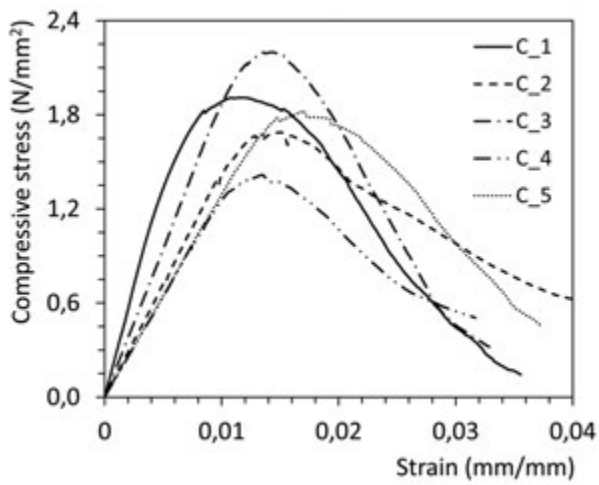

Fig. 7. Compressive stress vs strain curves of the 5 specimens from MB1 (by E. Garbin).

4. Discussion

The analytical investigations on mudbrick samples allowed to explore the composition, making technique and physical properties of these EBM.
The raw composition of the materials is standard. The addition of sand to the clay matrix as temper is a common solution to prevent shrinkage of the material during the drying. The sum of both natural inorganic (sand) and artificial inorganic inclusions (mortar fragments and grog) has been estimated between 30 and 40% of the samples, which is compatible with the standard amounts of inclusions in ancient mudbricks[22]. On the other hand, the vegetal tempers, which are considered the best stabilizers for incrementing the mechanical properties and the plasticity of mudbricks[23], are rare and their occurrence is probably accidental, as negative traces of straw are limited in respect to other cases[24].

22 Montana 2011.
23 Kemp 2000; Binici, Aksogan, Shah 2005; Quagliarini, Lenci 2010.
24 See for example the abundant use of seagrass in Bronze Age Cretan mudbricks, demonstrate the sophisticated know-how of Minoan builders about the physical properties of construction materials (Devolder, Lorenzon 2019; Lorenzon 2021a). See also Kemp 2000, 82, on the abundant amount of straw and chaff added to Egyptian mudbricks.

Sample	Apparent density	Compressive strength	Modulus of Elasticity
	(g/cm3)	(MPa)	(MPa)
1	1,7	1,91	275,18
2	1,74	1,69	146,05
3	1,74	2,2	191,1
4	1,72	1,42	131
5	1,7	1,82	131,91
Average values (CoV)	1.72 (1.24%)	1.81 (15.91%)	175.05 (34.89%)

Tab. 3 - Compressive strength and modulus of elasticity of the quasi-prismatic samples extracted from MB1.

The results of the analysis provide interesting data on the drying method. A common opinion is that mudbricks were naturally sun-dried for some time before being used in construction. One aspect which has been little investigated is the possibility that mudbricks could have been not (or not-only) sun-dried but heated in ovens at low temperatures, thus producing a sort of "half-fired brick". This possibility has been rarely considered in literature[25]. In fact, in all the cases in which evidence of combustion have been detected, the common idea was that mudbricks undergone an accidental conflagration[26]. No signs of firings have been documented in the excavation of the Middle-Imperial building of Nora, so the hypothesis of an accidental firing of the material can be excluded. On the other hand, if the mudbricks have been heated in ovens for some time, sample MB1-RC should represent the most oxidized portion, while MB1-BC the less exposed one. Nevertheless, this hypothesis must be corroborated by further data: the absence of kaolinite could depend on the instrumental limit due to the dilution of the original clay phase in the XRPD profile, while the different colours and the presence of hematite in the samples could simply rely on the mineralogical features of different types of clays as they occur in nature.
Mechanical compression test was decisive to determine the actual resistance of the mudbricks to physical stress. The test indicated good load-bearing capabilities of the samples. An average UCS value of 1,8 MPa is in line with the typical resistance of historical adobe constructions and even better than most part of ancient mudbricks which are usually belove the average of 1,6 MPa[27]. The unconfined resistance to compression of the analysed mudbrick is compatible with the construction of low-rise buildings[28].

[S.D.]

5. Conclusions

In this paper we provided new data about the characteristic and properties of earthen-based building materials in Nora and we gathered new information to improve our proposal for the reconstruction of the original elevation of the Middle Imperial building.
In a preliminary analysis of a large fragment of a concrete pavement collapsed from the first floor of the building, tested with the same compression techniques we adopted in this study, its load-bearing capacity and weight was described. On the basis of these data, a preliminary hypothesis about the resistance of the masonry walls has been proposed[29]. Other information about the conforma-

25 During the excavation of the Republican walls of Arezzo, Pernier (Pernier 1920, 185-186) reports the presence of half-fired adobes used in the construction. Unfortunately this hypothesis has not been further corroborated by analytical investigations.
26 Lorenzon 2021b; Nodarou, Fredrick, Hein 2008.
27 Quagliarini, Lenci, Iorio 2010; Liberotti et al. 2016; Aguilar, Montesinos, Uceda 2017; Aguilar et al. 2018; Liberotti 2021. Nevertheless, these measures cannot be taken as definitive as it has been demonstrate that shape and dimension (in particular high-to-weight ratios) of the sample can influence the results of the test (Illampas, Iannou, Charmpis 2014).
28 Achenza, Sanna 2011; Silveira et al. 2012.
29 Giatreli 2019; Giatreli 2020.

tion of the building were provided by the study of the collapsed wall-painting fragments, such as the presence of painted false ceilings in the main rooms and frescoes of the first floor collapsed over the ground floor.

The analysis we performed in this research, although limited, strengthen the hypothesis of a two-storey building, thus corroborating the theory of the previous research. Mudbricks produced in Nora during the Middle Imperial age seem to display good load-bearing capabilities. Nonetheless, the production of the mixtures was not standardized and the addition of vegetable tempers apparently did not modified the final physic-mechanical properties of the material.

In future works, it will be necessary to increase the number of sampled mudbricks in order to verify some of the working hypotheses we anticipated here. In particular, it will be necessary to investigate in detail the kind of heating treatment the material was object of (sun-drying or low-heating in oven), which is an argument seldomly discussed in literature. Furthermore, sampling should be expanded not only in statistical terms but also diachronically: the production of the EBM are deeply rooted in Nora since the Phoenician times and it continued in Sardinia even in modern times. Further indept analyses and sampling activities in the ancient Nora might allow to better define the terms for the technological innovation and the survival of building traditions in this cultural and geographical framework.

[S.D., A.Z.]

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Riassunto
Lo scavo archeologico di un complesso di età medio-imperiale situato a E del foro di Nora (Pula, Sardegna), diretto dal Dipartimento di Beni Culturali dell'Università di Padova, ha restituito attestazioni di muri in mattone crudo in stato di crollo.
L'obiettivo della presente ricerca è l'analisi delle caratteristiche dei mattoni crudi attraverso un approccio multi-analitico che integra indagini archeometriche (microscopia ottica a luce trasmessa e diffrazione delle polveri ai raggi X) e prove meccaniche di compressione eseguite presso i laboratori del Dipartimento di Geoscienze e del Dipartimento di Ingegneria Civile, Ambientale e Architettura dell'Università di Padova.
Sfortunatamente, una serie di eventi post-deposizionali ha causato la sostanziale disaggregazione dei muri in crudo, tanto da renderli difficilmente distinguibili all'interno della matrice argillosa che costituisce il deposito archeologico stesso. Questo fatto ha costituito il problema principale della ricerca, dato che le analisi sono state limitate a due soli elementi di mattone crudo sufficientemente coesi.
I risultati delle analisi hanno dimostrato come entrambi gli elementi analizzati siano stati prodotti miscelando argille locali con un'abbondante frazione sabbiosa smagrante. I mattoni così prodotti vennero successivamente essiccati al sole ma non si esclude che possano essere stati scaldati in forni a bassa temperatura. I test meccanici indicano una resistenza alla compressione monoassiale di circa 1,8 MPa, che può essere considerata compatibile per un edificio a due piani.
Grazie a queste indagini è stato possibile trarre dati utili circa le materie prime, i processi di produzione e l'impiego dei mattoni crudi in Sardegna nel corso dell'Età romana.
Parole chiave: Mattone crudo, Test meccanici, XRPD, Microscopia Ottica, Nora

Abstract
The archaeological excavation, directed by the Department of Cultural Heritage of the University of Padova, of a Middle Imperial building located east of the forum of Nora (Pula, Sardinia), provided evidence of collapsed mudbrick walls.
The target of the present research is the analysis of the characteristics of mudbricks, throughout a multi-analytical approach integrating archaeometric investigations (transmitted light optical microscopy and X-Ray Powder Diffraction) and mechanical compression tests performed at the laboratories of the Department of Geosciences and of the Department of Civil, Environmental and Architectural Engineering of the University of Padova.
Unfortunately, post-depositional events caused the substantial mechanical disaggregation of mudbrick walls to such an extent that they were hardly distinguishable within the clayish matrix constituting the archaeological deposit. This represented the main issue of the research as the analyses were limited to only two sufficiently cohesive mudbricks.
The experimental outcomes highlighted that both the analysed elements were produced by mixing local clays with an abundant sand fraction. Then they were sundried or, possibly, heated in ovens at low temperatures. Mechanical

tests indicated an unconfined compressive strength of about 1.8 MPa, which can be considered compatible with the construction of a two-storey building.
The investigations provided useful data for the possible reconstruction of raw materials and production process of mudbricks in Roman Sardinia, and of their use in low-rise buildings.
Keywords: Mud Bricks, Mechanical tests, XRPD, Optical Microscopy, Nora

Simone Dilaria
Università degli Studi di Padova, Dipartimento dei Beni Culturali: Archeologia, Storia dell'Arte, del Cinema e della Musica
Assistant Professor (RTD-A)
Piazza Capitaniato, 7 - 35139 - Padova
simone.dilaria@unipd.it

Enrico Garbin
Università degli Studi di Padova, Dipartimento di Geoscienze
Post-doc
Via G. Gradenigo, 6 - 35131 - Padova
enrico.garbin@unipd.it

Lara Maritan
Università degli Studi di Padova, Dipartimento di Geoscienze
Associate Professor
Via G. Gradenigo, 6 - 35131 - Padova
lara.maritan@unipd.it

Arturo Zara
Università degli Studi di Padova, Dipartimento dei Beni Culturali: Archeologia, Storia dell'Arte, del Cinema e della Musica
Post-Doc
Piazza Capitaniato, 7 - 35139 – Padova
arturo.zara@unipd.it